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TECHNICAL NOTE 3894

A STUDY OF THE IMPACT BEHAVIOR OF HIGH-TEMPERATURE MATERIALS

By H. B. Probst and Howard T. McHenry

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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SUMMARY

The impact properties of titanium carbide base cermets, some high-temperature alloys, and the intermetallic, NiAl, were obtained at room and elevated temperatures to 1750° F. The impact energies of cermets were found to increase with increased amounts of metallic binder. The composition of an alloy binder influenced the resistance to impact failure. As might be expected, this influence may be beneficial or detrimental, depending on the particular alloy. Less angular carbide particles resulted in an improved impact strength of cermets, which was only slightly affected by test temperature. The general trend was a decrease in impact strength with increased temperature.

Within the range of notch radii investigated, a cermet composition showed continuous decreasing impact resistance as the notch radius of the test bar was decreased. When cermets and alloys were compared on the basis of impact resistance, most cermets were less resistant to impact failure than brittle alloys.

Variables such as gripping force, gripping material, and repeated blows that affected the impact resistance measured by the drop test are discussed, and a modified specimen supporting arrangement to eliminate the first two variables is presented.

INTRODUCTION

On the basis of creep and stress-rupture data, cermets exhibit properties that promise to allow the operating temperature of turbine blades to be increased (ref. 1). Encouraging results have also been obtained in engine runs (ref. 1). The engine runs have revealed, however, that upon failure of one cermet blade, the adjacent cermet blades are frequently severely damaged by the impact of fragments from the initially failed blade. Blades of current alloys are far superior to cermets in resisting this type of failure.

To ultimately improve the impact resistance of cermets, tests were initiated to measure the impact energy of 10 cermet compositions using both notched and unnotched test bars at room temperature and (for some of the materials) at 1200°, 1500°, and 1750° F. This report presents the results of these studies and indicates the relation of quantity and nature of metal and carbide phases to the impact resistance of these cermets. This impact resistance of cermets is compared with that of several high-temperature alloys.

Conventional impact machines have not proved suitable for evaluating cermets because of their low sensitivity and the inclusion of extraneous factors in the measured impact energy. "Toss energy," that is, the kinetic energy contained in the broken half of a specimen, has been reported to be a major factor in introducing errors into the measured impact resistance (refs. 2, 3, and 4). Work at this laboratory, however, has shown that the toss energy contributed by the test apparatus is a negligibly small value for cermets when tested by a low-capacity Izod pendulum (ref. 5). The NACA drop test (ref. 6), which eliminates the variable of toss energy, was used in this investigation. 4105

The materials described previously were evaluated by the NACA drop test. Several variables of the drop test were investigated, and modifications of this test were appraised and are described herein.

APPARATUS AND PROCEDURE

Conventional impact machines are not suited for evaluating cermets because they are not sufficiently sensitive at low impact energies, include extraneous energy factors in the measured impact resistance, require large specimens that are difficult to fabricate from experimental cermets, and yield considerable scatter in measured impact energies. This last point is true for ductile materials even when closely controlled testing conditions are used (ref. 7).

The NACA drop-test apparatus is shown schematically in figure 1(a), and a photograph is given in figure 1(b). This test consists of dropping a known weight from increasing heights until just enough energy is available to fracture the specimen. In this manner, excess energy and, therefore, toss energy contributed by the test apparatus are eliminated.

The specimens tested are shown in figure 2. The specimen is positioned in plates of transite that are gripped by the vise. In the test position, the specimen is a cantilever beam with the point of impact 1/8 inch from the free end, resulting in a bending moment arm of 7/8 inch. In testing notched specimens (bar A, fig. 2(a)) the small-radius notch is placed upward.

For high-temperature evaluation, the specimens are resistance-heated as shown in figure 1. The screen is used to improve electrical contact between the specimen and the movable electrode. The specimen is heated to approximately 25° F above the test temperature, at which time the movable electrode is moved out of position. As the specimen cools, the hammer is released at the instant the specimen reaches the desired test temperature. The hammer weights used in this study ranged from 0.2 to 1.8 pounds. Detailed operational procedure for the drop test may be found in reference 6.

During the course of the materials comparison program, as well as during an evaluation of the drop test by another laboratory (ref. 8), certain difficulties in the drop test became apparent. The principal difficulties were that the measured impact resistance was sensitive to gripping load, gripping material, and the number of impacts prior to fracture.

In order to eliminate the variables of gripping force and gripping material, two alternate methods of supporting the specimen were investigated and are shown schematically in figure 3. In the arrangement shown in figure 3(a), there is a possibility of losing contact at the bottom support farthest from the point of impact at the moment of impact. Therefore, the method shown in figure 3(b) was also used. In this case, complete contact is assured at the moment of impact. The fixtures are made of hardened steel. These methods were investigated at room temperature only.

MATERIALS

The materials evaluated are listed in table I. The alloys studied were chosen for various reasons: promising new alloys (Guy Alloy, 73-J, HE 1049, Inconel 550, and the molybdenum alloys), an alloy of very low strategic element content (35-100), and currently used and well-established alloys (HS-21 and X-40).

Since it was thought that the operating temperatures in an engine might cause embrittlement, the effect of time in engine runs on the impact resistance of HS-21 was also studied. This was done by machining impact test bars from the roots of turbine blades that had been run in full-scale engine tests. The root temperature is, of course, considerably less than the temperature of the airfoil during operation.

NiAl was tested to give some initial data for an intermetallic.

RESULTS AND DISCUSSION

Variables of Drop Test

The nature of the drop test requires that the specimen be struck repeated blows. This requirement and several other testing variables of the drop test are discussed in the following sections.

Effect of repeated blows. - Because of the brittleness of cermets and their negligible capacity for work hardening, it might be expected that the number of blows would not affect the fracture energy. However, data have been published (ref. 8) which show a definite weakening effect caused by an increased number of blows.

Effect of gripping force and gripping material. - Reference 8 shows measured impact energy to decrease as the gripping torque is increased. The impact energies of the cermet JR-6 corresponding to torques of 20, 50, and 80 inch-pounds were 7.1, 6.04, and 4.45 inch-pounds, respectively (ref. 8).

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The gripping force used in this study was intended to be constant and was produced by tightening the vise screw to a constant torque of 20 inch-pounds. This torque was applied with a torque wrench having a total capacity of 24 inch-pounds. To determine if the resultant force was constant, an electrical strain gage was attached to a piece of a plain carbon steel 1/4 by 1/4 by 1 inch which was then placed between the vise jaws with the long axis perpendicular to the face of the jaws. A nickel insert was placed between the top of the steel bar and the upper vise jaw and a transite plate placed between the bar and lower vise jaw to give the same gripping conditions as used in the drop test. The vise was repeatedly tightened with the torque wrench, and the resulting strain in the bar measured by the strain gage. With the strain and the elastic modulus of the bar known, the stress in the bar and the corresponding force between vise jaws were calculated for each tightening of the vise. This force varied from 220 to 370 pounds for the constant applied torque of 20 inch-pounds. This variation is attributed to differences in the degree of lubrication of the vise screw and deformation of the transite plate. The resulting changes in indicated impact resistance caused by this load variation are, of course, much smaller than those reported in reference 8 where the gripping load (applied torque) was intentionally varied.

The transite plate is required to insulate the specimen during high-temperature testing. Transite deforms with each blow to the specimen and absorbs energy in doing so. Therefore, any variation in the properties of the transite will affect the measured impact resistance of a given material. Base plates cut from two different pieces of transite were found to have different hardnesses. By using a 500-kilogram load, a 10-millimeter ball, and a 10-second load application time, the Brinell hardnesses of the two pieces were determined to be 54 and 24. This hardness difference is sufficient to cause major differences in performance in the drop test and thus affect the measured impact energy of a test material. For example, unnotched JR-6 required 11.1 inch-pounds for fracture when the hard transite was used. When the softer transite was used this material could not be fractured at the full test capacity of 62 inch-pounds.

All data presented herein were obtained using hard transite plates cut from one original piece of transite.

Stress-free supporting of specimen. - In order to eliminate the variables of gripping force and gripping material, two stress-free methods of supporting the specimen were tried (fig. 3).

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The stress-free supporting arrangement shown in figure 3(b) results in a constant maximum bending moment over the length of the specimen between the two central loading points, a distance of 1/2 inch. This is true for the arrangement shown in figure 3(a) only if complete contact is maintained as previously discussed. With the vise, the maximum bending moment exists on a plane at the vise jaw. Having the maximum bending moment exist over this 1/2-inch span subjects a greater portion of the specimen to the maximum stress. With this situation, the specimen will now fail at the weakest point within this span. This is a favorable condition which should result in increased uniformity of test results.

Table II compares the impact energies of K152B as measured by the stress-free supporting methods to those measured when the vise grip was used. The difference in impact energies measured by methods A and B is explained by the geometry of the two systems. For a given load, the bending moment on the specimen in method A is twice the bending moment of method B. Therefore, the specimen of method B is theoretically able to sustain twice the impact load of method A.

The average impact resistance of K152B using method A is the same as that obtained by using the vise grip. Method B shows fair agreement with method A when this difference in geometry is considered.

Both methods A and B greatly reduced the range of scatter from that of the vise grip, thus permitting the determination of the impact resistance of a material with greater accuracy or by the use of a smaller number of specimens. The possibility exists here of realizing a large savings in specimen manufacture. These tests are somewhat more tedious to perform, however, as on each impact the parts are thrown and must be realined before the next drop of the hammer.

The advantages of these tests were, unfortunately, not discovered until after the materials comparison program was completed. Although all material data reported herein were obtained using the vise gripping method, the results are reliable because of the use of a sufficiently large number of specimens.

Impact Resistance of Cermets

Comparison of impact energies. - The results obtained with the drop test are presented in table III. In most cases, these values represent the average of six specimens. The first one or two specimens of a group of six received a relatively large number of blows before fracture because the level of impact resistance was totally unknown at this point in the test procedure. Each succeeding specimen received fewer blows as the level of impact resistance for the particular test material was indicated from previous specimens. In this manner, the effect of repeated blows on impact resistance was held to a minimum. (Specimens shown in fig. 2 were used as noted in table III.)

While the data of table III were being collected, two of the major variables in the drop test (repeated blows and variations in gripping force) were in operation. The effect of the third major variable, gripping material, was minimized by using transite base plates cut from the same piece of transite. In spite of the variables of repeated blows and variations in gripping force, the scatter band for any one test material was not unduly large, and the differences shown between materials are significant.

Comparing the cermets tested (table III) show that TC-66-I and JR-6 are superior to the others. The data for JR-6 were obtained using a specimen with a slightly smaller cross section than was used for the majority of the other data. The TC-66-I was produced by infiltration while the JR-6, as well as all the other cermets reported herein, was produced by cold pressing and liquid phase sintering.

A portion of the results of this investigation shows similar trends and is comparable in magnitude to data obtained by Thompson Products, Inc. To make a comparison with these data, however, it is necessary to make a correction for differences in moment arms, that is, the distance from poin of impact to fracture surface. The drop test employed by Thompson Product used a 1/2-inch moment arm as compared with a 7/8-inch arm used in this study. A comparison of the Thompson Products results with those of this study was made by using the relation that moment arm multiplied by impact energy is approximately a constant for a given material and specimen cross section. This relation was verified by a few preliminary tests.

Effect of amount of binder. - A cermet consists of two components, a brittle ceramic and a ductile metal. As the amount of ductile metal binder in a cermet is increased, the impact resistance would be expected to increase. Figure 4 shows the resulting microstructures of titanium carbide base cermets containing 10 percent nickel (K150B), 30 percent nickel (K152B), and 50 percent nickel (K154B). The data of figure 5 show the corresponding increases in impact resistance.

Effect of binder composition. - Reference 9 shows that the wettability of the carbide is improved by the addition of molybdenum to the nickel binder, which results in a finer carbide particle size and increased impact resistance at room temperature. Comparison of K152B (30 percent nickel) and K162B (25 percent nickel, 5 percent molybdenum), both having the same amount of binder (no significant change in the volume percentage of binder is present in these two cermets), confirms the room-temperature data of reference 9, that is, K162B is superior. However, this superiority is not maintained at 1200° F.

On the other hand, comparison of FS-9 (30 percent nickel, 10 percent cobalt, 10 percent chromium) to FS-27 (50 percent nickel) illustrates that improvement of impact properties at both room and elevated temperatures by the use of an alloy binder is possible.

In comparing JR-6 (46 percent nickel, 2 percent aluminum, and 2 per percent molybdenum) to JR (33.8 percent nickel, 12.7 percent molybdenum, and 3.5 percent aluminum), a contradictory trend can be observed. It can be noted that the increased alloying of the nickel binder resulted in a decrease in impact strength. Thus, at the present time, it is not possible to predict the impact strength of a cermet on the basis of the binder composition.

Effect of carbide particle shape. - The infiltrated cermet, TC-66-I, has significantly higher impact resistance at all temperatures than most of the other cermets investigated (table III). The microstructure of this cermet is shown in figure 6. The carbide particles are less angular than those of the other cermets shown in figure 4. These less angular carbide particles do not act as stress risers to the same extent as the angular particles. Thus, with fewer points of high stress concentration, the impact resistance is improved. The effect of an alloy binder is also operating here to an unknown extent. The microstructure of the TC-66-I material was significantly different from that of the other cermets, as was described previously. Upon completion of the impact tests the fragments of the JR-6 specimens were immediately returned to the supplier, and, thus, the microstructure could not be examined.

Effect of temperature. - The impact resistance of cermets, as shown in table III, is little affected by an increase in testing temperature. The indefinite trend noted is toward a decrease in impact energy with increasing temperature. The cermets exhibiting the greater decreases are K162B, JR, and JR-5. It is encouraging to note, however, that cermets K154B and FS-9 actually gained in impact resistance at the higher temperatures.

Effect of stress concentration. - The effect of notch radius on the impact properties of K152B was studied by varying the upper notch radii of test specimens. The lower-notch radius was held constant at 0.250 inch. The upper notch was machined to radii corresponding approximately to those used in the root sections of some cermet turbine blades (ref. 10). The thickness between notches and notch depth were held constant.

The results of the present investigation are given in figure 7 where impact energy is plotted as a function of notch radius. The curves show a decreasing impact resistance as the notch is made more severe over the entire range of notch radii from 0.311 to 0.031 inch. This stress concentration effect of the notch is less severe at higher temperatures.

High-Temperature Alloys

Impact energies of some of the more conventional alloys and new high-temperature alloys are given in table III.

The room-temperature value for as-cast X-40 (AMS 5382) as determined by the NACA drop test falls within the same range of values obtained using the standard Tinius-Olsen pendulum (ref. 11). There is, however, a difference in specimen geometries used in the two tests. The drop-test data were obtained using bar A (fig. 2), while the data obtained using the standard pendulum test in reference 11 are for bar C (fig. 2).

Table III gives impact energies of HS-21 specimens which were machined from roots of blades engine tested for various times. The impact resistance of HS-21 is essentially constant regardless of time in engine runs.

Room-temperature impact energies for the molybdenum alloys are also given in table III. These data indicate a high degree of notch sensitivity in molybdenum alloys. Room-temperature data for notched molybdenum alloys are also given in reference 12. There is little agreement in comparing the impact resistance of notched bars reported herein with those of reference 12. There is no apparent explanation for this lack of agreement.

From the standpoint of impact resistance, Inconel 550 and Guy Alloy appear to be the best of the new high-temperature alloys tested in this investigation. From room temperature to 1500° F NiAl, 35-100, and HE-1049 were relatively brittle.

Comparison of Cermets and Alloys

A comparison of the cermets and alloys investigated is made by grouping the materials into certain ranges of impact resistance. The lowest range has maximum notched and unnotched impact energies of 3.7 and 10.3 inch-pounds, respectively. In this group are cermets K150B, K152B, K154B, K162B, FS-9, FS-27, JR, and JR-5, brittle alloys 35-100, HE-1049, and the intermetallic NiAl.

The next range has maximum impact energies of 12.9 and 27.7 inch-pounds for notched and unnotched bars, respectively. The most impact-resistant cermets tested, TC-66-I and JR-6, and alloys 73-J and Guy Alloy, are in this range.

The third range, which includes any values greater than the limits of the second range, contains Inconel 550, HS-21, X-40, and the molybdenum alloys. At the present time, there are no cermets in this range.

CONCLUDING REMARKS

The NACA drop test is capable of showing trends and differences in impact energies of brittle materials but has certain shortcomings. The fatiguing action of repeated blows can be minimized by prudent testing procedure using a sufficient number of test bars. Variations in gripping force and gripping material may be eliminated by the use of stress-free specimen supporting devices. The use of these devices also results in a significant reduction in the scatter of impact values.

The impact resistance of titanium carbide base cermets was affected in the following ways:

1. Impact resistance increased as the amount of metallic binder was increased.

2. The composition of the binder affected impact resistance. As might be expected, the effect may be either beneficial or detrimental, depending on the particular binder.

3. For the test-bar geometry used here, the cermets showed continuously decreasing impact resistance within the range of notch radius from 0.311 to 0.031 inch.

4. The most impact-resistant cermets tested, TC-66-I and JR-6, compared favorably with certain experimental alloys of very limited ductility. The improvement in impact resistance of TC-66-I, fabricated by infiltration, is attributed mainly to the less angular carbide particle. It is probable that at least a part of the increase in impact resistance for JR-6 and TC-66-I resulted from the composition of the alloy binder.

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Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 13, 1956

REFERENCES

1. Ault, G. Mervin, and Deutsch, George C.: Review of Materials for Jet Engines. NACA-University Conference on Aerodynamics, Construction, and Propulsion. Vol. I - Aircraft Structures and Materials. Lewis Flight Propulsion Lab., Nat. Advisory Committee for Aero., Oct. 1954.

2. Callendar, L. H.: New Methods for Mechanical Testing of Plastics. British Plastics, vol. 13, Apr. 1942, pp. 445-458.

3. Maxwell, Bryce, and Rahm, L. F.: Impact Testing of Plastics: Elimination of the Toss Factor. A.S.T.M. Bull., No. 161, Oct. 1949, pp. 44-47; discussion, pp. 47-48.

4. Stock, Charles R.: A Ball Impact Tester for Plastics. A.S.T.M. Bull., No. 130, Oct. 1944, pp. 21-26.

5. Probst, H. B., and McHenry, Howard T.: A Study of the "Toss Factor" in the Impact Testing of Cermets by the Izod Pendulum Test. NACA TN 3931, 1957.

6. Pinkel, B., Deutsch, G. C., and Katz, N. H.: A Drop Test for the Evaluation of the Impact Strength of Cermets. NACA RM E54D13, 1955.

7. Metallurgical and Research Committee of the Forging Manufacturers Association: How Accurate is the Impact Test? Metal Prog., vol. 60, no. 6, Dec. 1951, pp. 69-71; con't., p. 176.

8. Soxman, E. J., Curran, M. T., and Tinklepaugh, J. R.: Impact Testing of Cermets. Prog. Rep. No. 2, July 1 to Oct. 1, 1954, The New York State College of Ceramics, Alfred Univ., Alfred (N. Y.). (Contract No. AF33(616)2380.)

9. Humenik, Michael, Jr., and Parikh, Niranjan M.: Cermets: I, Fundamental Concepts Related to Microstructure and Physical Properties of Cermet Systems. Jour. Am. Ceramic Soc., vol. 39, no. 2, Feb. 1, 1956, pp. 60-63.

10. Meyer, André J., Jr., Kaufman, Albert, and Calvert, Howard F.: Comparative Tensile Strengths at 1200° F of Various Root Designs for Cermet Turbine Blades. NACA RM E53C25, 1953.

11. Anderson, W. J.: Impact Strength of Titanium-Carbide Cermets at 70F, 1600F, and 1800F. Rep. No. B-7606, Pratt and Whitney Aircraft, East Hartford (Conn.), Nov. 13, 1953.

12. Barr, Robert: Behavior of Unalloyed Molybdenum and Some Molybdenum-Base Alloys in a Special Impact Test. Rep. No. 3180, Climax Molybdenum Co., Dec. 22, 1953.

TABLE I. - MATERIALS USED FOR IMPACT EVALUATION

Designation	Nominal composition, percent by weight	Supplier
	Conventional alloys	
HS-21[a]	27 Cr, 2.8 Ni, 5.5 Mo, balance Co	Haynes-Stellite
X-40[b]	25.5 Cr, 10-5 Ni, 7.5 W, balance Co	Haynes-Stellite
	Experimental alloys	
Inconel 550[b]	0.05 C, 15 Cr, 0.73 Mn, 6.6 Fe, 1.16 Al, 2.5 Ti, 0.007 S, 1.03 NbTa, 0.28 Si, 0.03 Cu, balance Ni	Air Force
35-100[b]	35 Ni, 28 Cr, 31 Fe, 1.5 Mn, 0.5 Si, 7.9 Mo, 0.6-1.1 C, 0.1-0.2 B	International Nickel Co.
HE-1049[b]	10 Ni, 26 Cr, 15 W, 3 Fe, 0.8 Si, 0.4 C, 0.4 B plus 44 Co	Haynes-Stellite
Guy Alloy[b]	12-15 Cr, 0.5 Mn, 0.5 Si, 5-6 Mo, 5.5-7 Al, 2 Nb, 0.5 B, 4-5 Fe, 0.1 C, balance Ni	Cast at NACA
73-J[b]	23 Cr, 6 Ni, 6 Mo, 0.7 C, 1.0 Mn, 2.0 NbTa, balance Co	M.I.T., Precision Casting Co.
	Molybdenum alloys[c]	
937	0.015 C, balance Mo	Climax Molybdenum Co.
988	0.019 C, 0.24 Nb, balance Mo	Climax Molybdenum Co.
1133	0.014 C, 0.85 Ti, balance Mo	Climax Molybdenum Co.
1252	0.003 C, 0.15 Al, balance Mo	Climax Molybdenum Co.
	Cermets	
K150B	10 Ni, 8(NbTaTi)C, balance TiC	Kennametal
K152B	30 Ni, 8(NbTaTi)C, balance TiC	Kennametal
K154B	50 Ni, 8(NbTaTi)C, balance TiC	Kennametal
K162B	25 Ni, 5 Mo, 8(NbTaTi)C, balance TiC	Kennametal
TC-66-I	50 Inconel, 50 TiC	Thompson Products, Inc.
FS-9	30 Ni, 10 Co, 10 Cr, balance TiC	Firth Sterling
FS-27	50 Ni, 7.1 Cr_3C_2, balance TiC	Firth Sterling
JR	33.8 Ni, 12.7 Mo, 3.5 Al, 8(NbTaTi)C, balance TiC	Kennametal
JR-5	27 Ni, 10.2 Mo, 2.8 Al, 6(NbTaTi)C, balance TiC	Kennametal
JR-6[d]	46 Ni, 2 Mo, 2 Al, 4(NbTaTi)C, balance TiC	Kennametal

[a]Machined from stock blade after engine evaluation.
[b]Machined from new blade roots.
[c]Machined from 5/8-in. diam. bar stock.
[d]Run at request of Alfred University.

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TABLE II. - EFFECT OF STRESS-FREE SUPPORTING ON

IMPACT ENERGY (IN.-LB) OF UNNOTCHED K152B

Specimen supporting arrangement			
Vise		Stress-free, method A	Stress-free, method B
	5.0	4.2	7.9
	3.6	4.3	7.9
	4.4	4.4	7.5
	4.3	4.0	---
Av.	4.3	4.2	7.7
Range	1.4	0.4	0.4

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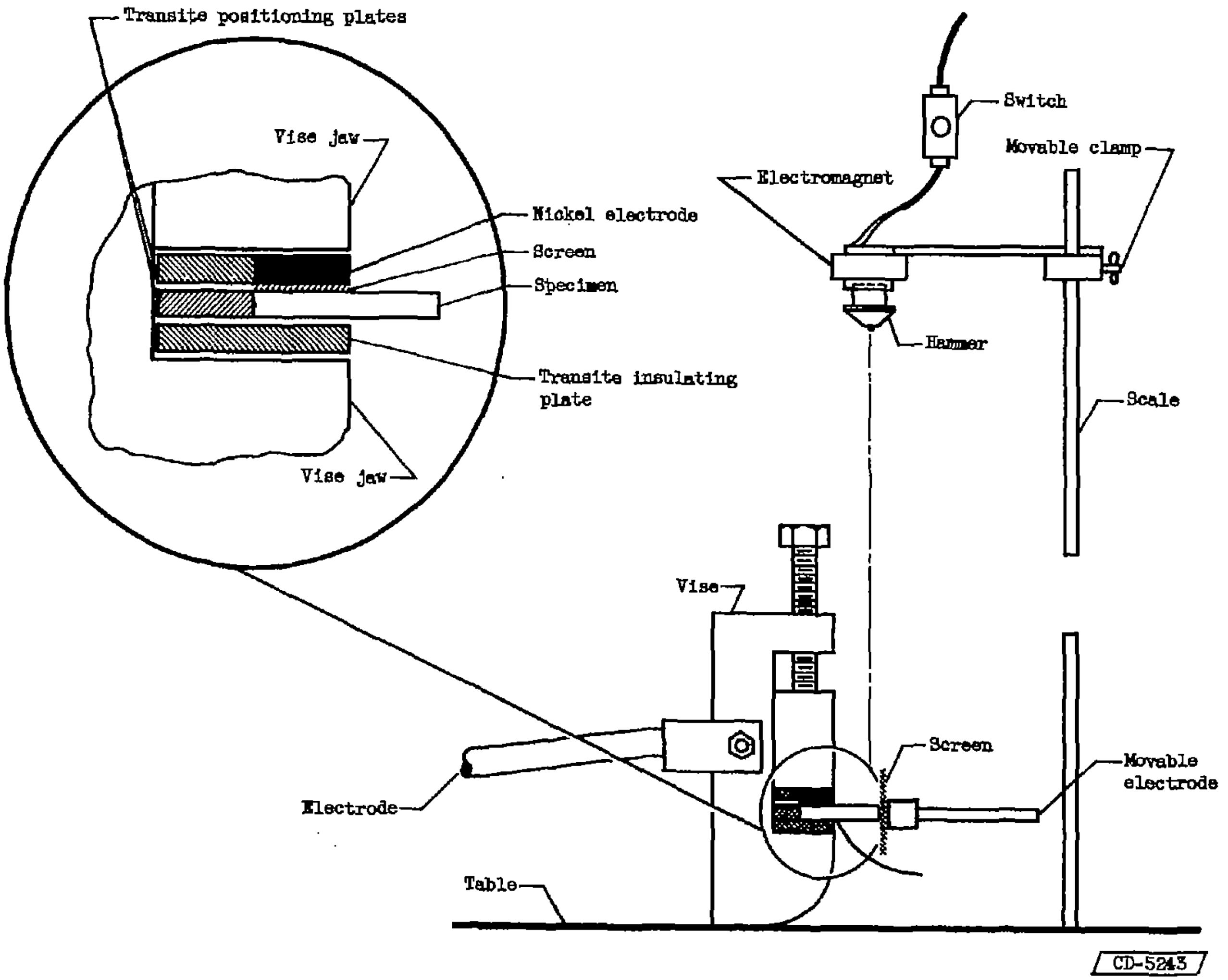
TABLE III. - AVERAGE IMPACT RESISTANCE (IN.-LB) OBTAINED ON NACA DROP TEST

Material	Temperature, °F								Remarks
	Room		1200		1500		1750		
	Notched	Unnotched	Notched	Unnotched	Notched	Unnotched	Notched	Unnotched	
Conventional alloys									
									Time run in engine, hr
X-40	48.0								
HS-21 43-4300	41.7								108.42
HS-21 41-4300	42.6								104.19
HS-21 15-4300	43.3								168.20
HS-21 12-4300	42.7								231.20
HS-21 36-4300	40.8								295.25
HS-21 30-4300	45.3								268.40
HS-21 22-4300	44.5								301.52
Experimental alloys									
Inconel 550	[a]>62.0		[a]>62.0		[a]>62.0				As received
Inconel 550	25.8		56.0						Heat treated
NiAl	3.6	10.3			2.6				
35-100	1.6	1.9		2.5		2.5			
HE-1049	3.7		3.2		4.5				
Guy Alloy 73J	12.9	16.7	15.2	22.7					
Molybdenum alloys									
937	14.5	27.1							All molybdenum alloys were stress-relieved 1 hr at 1800° F
988	16.7	39.7							
1133	24.4	[a]>62.0							
1252	13.0	[a]>62.0							
Cermets									
K150B	1.3	1.4	1.0	1.1	0.6	1.5	0.4	1.4	
K152B	2.1	[b]4.2 4.1	1.6	[b]4.3 3.7	1.6		1.6		
K154B	2.8	5.2	2.3	5.2	2.3	5.5	3.8	5.6	
K162B	3.3	6.3	1.3	2.6					
TC-66-I		12.4		12.8		11.9		9.2	Infiltrated
FS-9	1.9		2.4		2.5				
FS-27	1.3		1.4		1.3				
JR	2.3	5.5	1.2	3.2	1.0				
JR-5	1.7	3.6	1.3	2.6	.9				
JR-6		[b]11.1						[b]10.8	

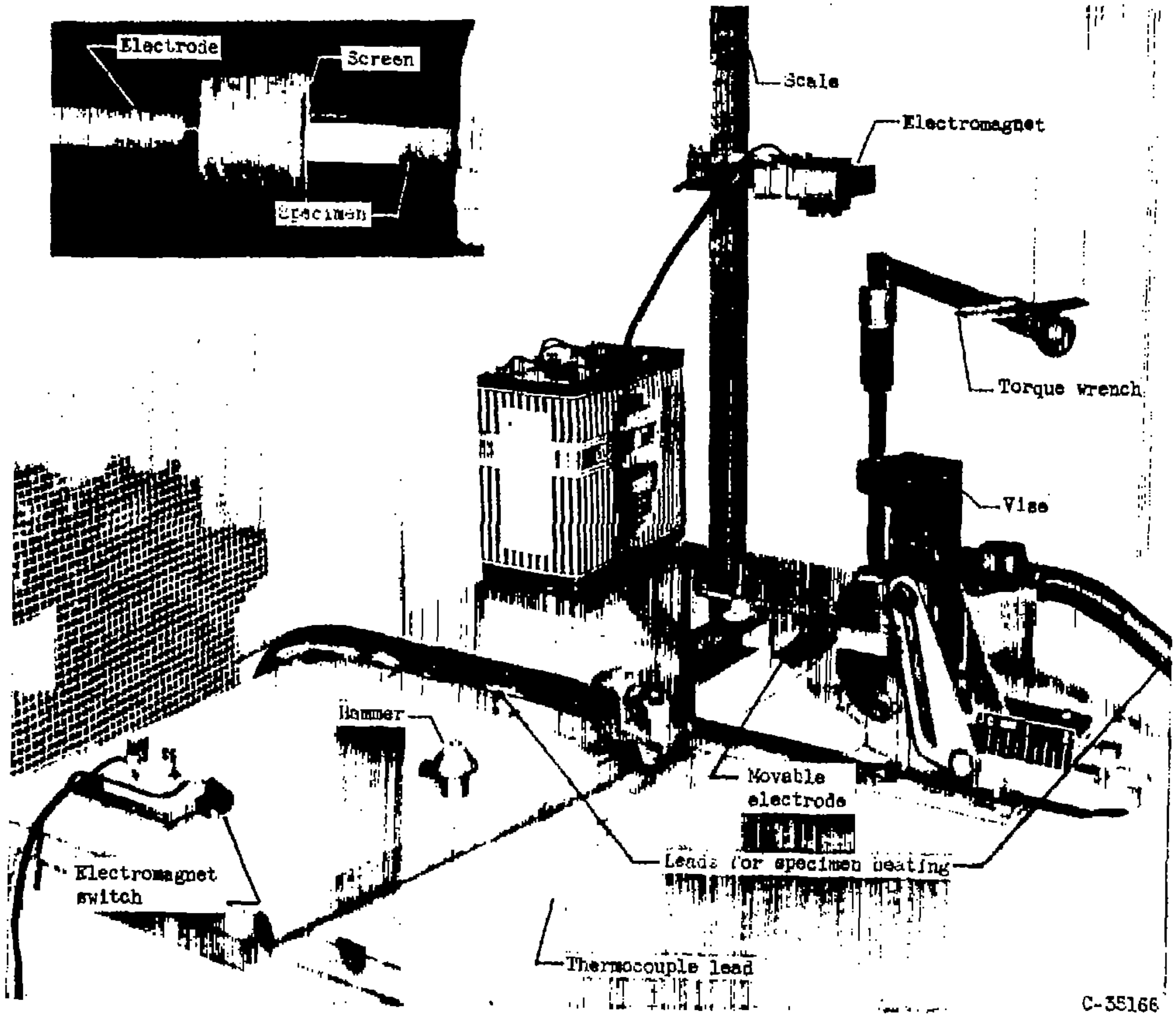
[a]Maximum capacity of drop test.

[b]Values for bar C; $\frac{3}{16}$ by $\frac{3}{16}$ by $1\frac{1}{2}$ in.



(a) Schematic diagram.

Figure 1. - NACA drop-test apparatus.



(b) Over-all view.

Figure 1. - Concluded. NACA drop-test apparatus.

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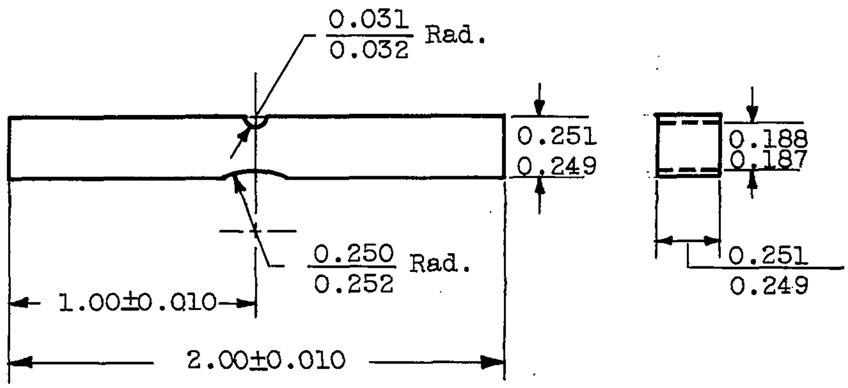
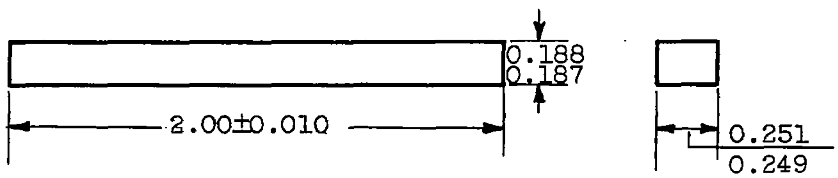
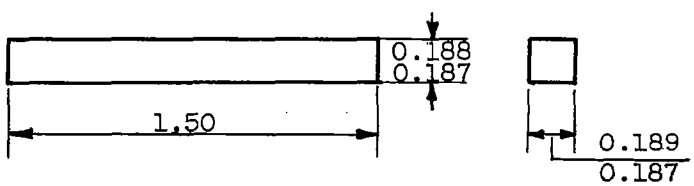


(a) Bar A ; notched impact test bar.

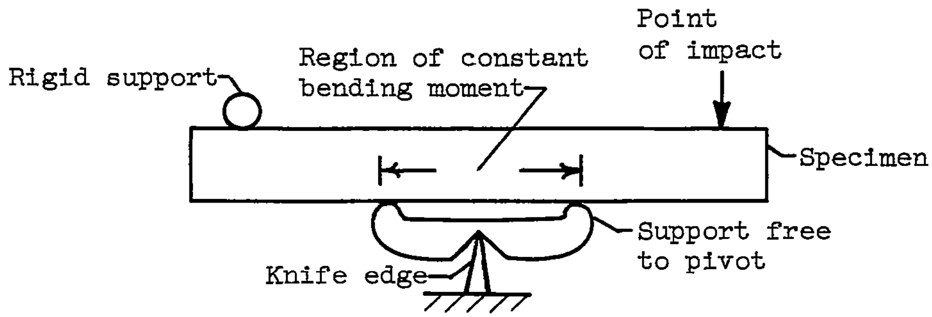


(b) Bar B; unnotched impact test bar.

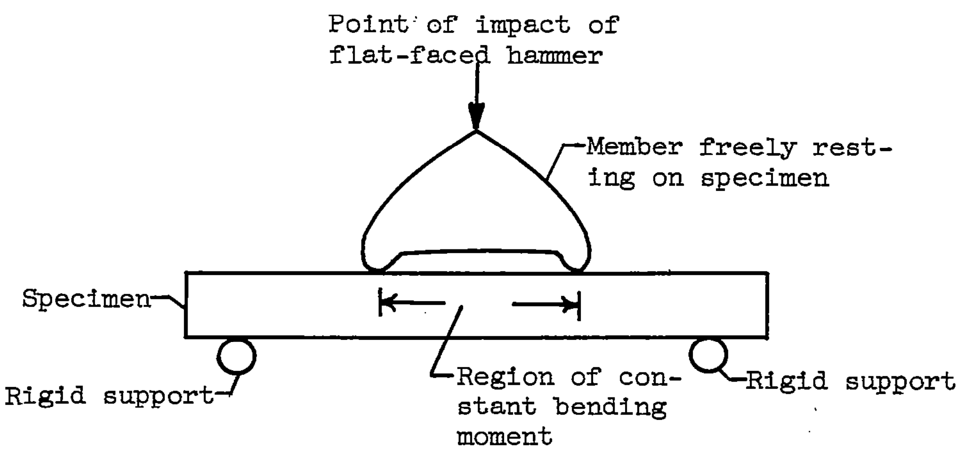


(c) Bar C; tentative standard impact test bar. (Suggested at Cermet Impact Conference, Alfred U., Feb., 1954.)

Figure 2. - Impact specimens. (All dimensions in inches.)



(a) Method A.



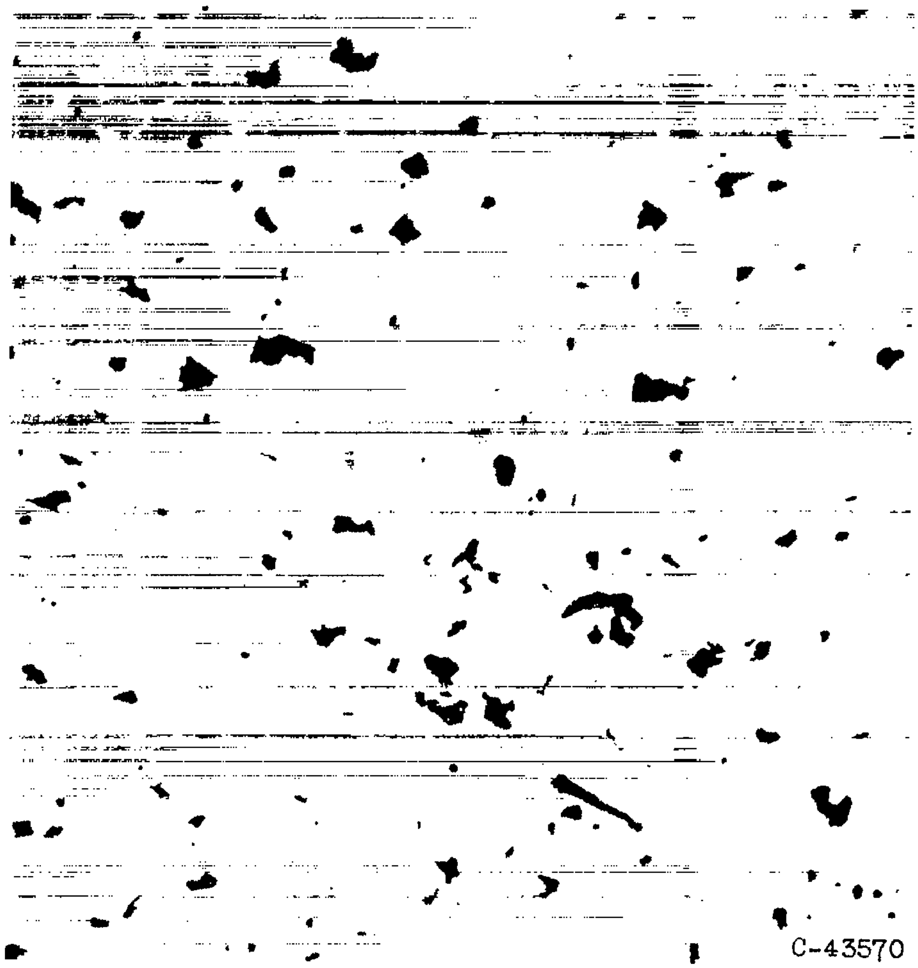
(b) Method B.

Figure 3. - Schematic view of stress-free supporting arrangements.

4105

CD-3

4105

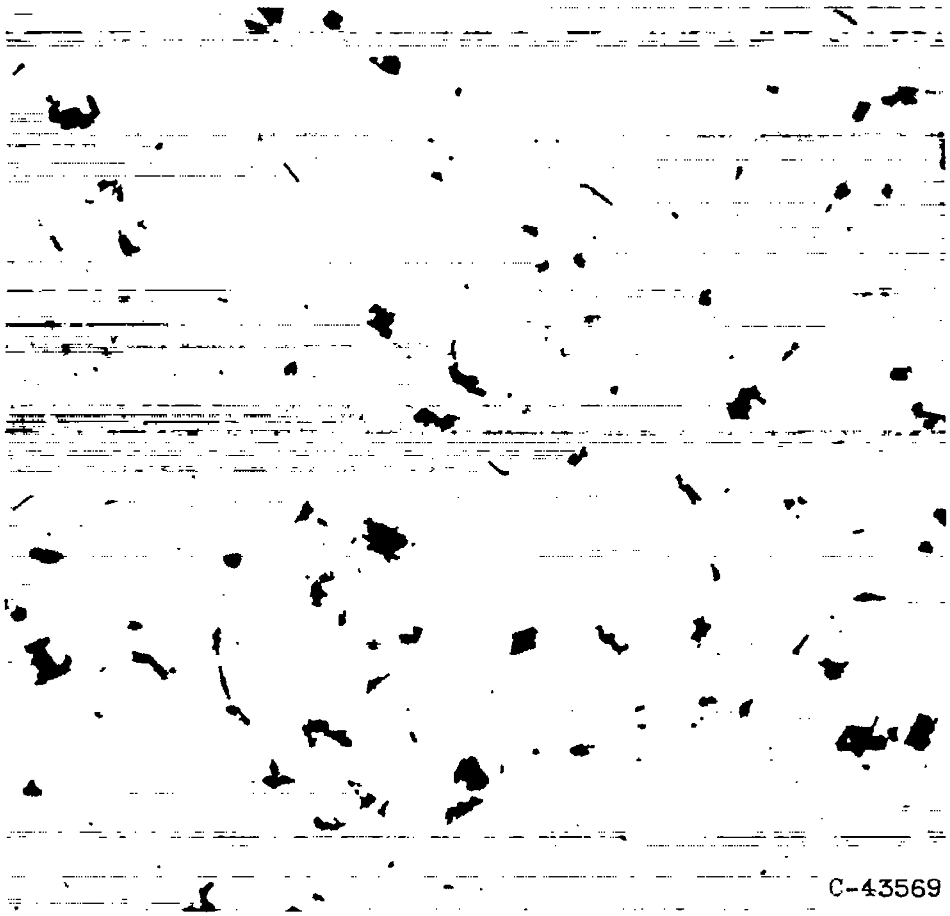


(a) K150B (10 percent nickel).

Figure 4. - Microstructure of various titanium carbide base cermets. Unetched; X1000.

4105

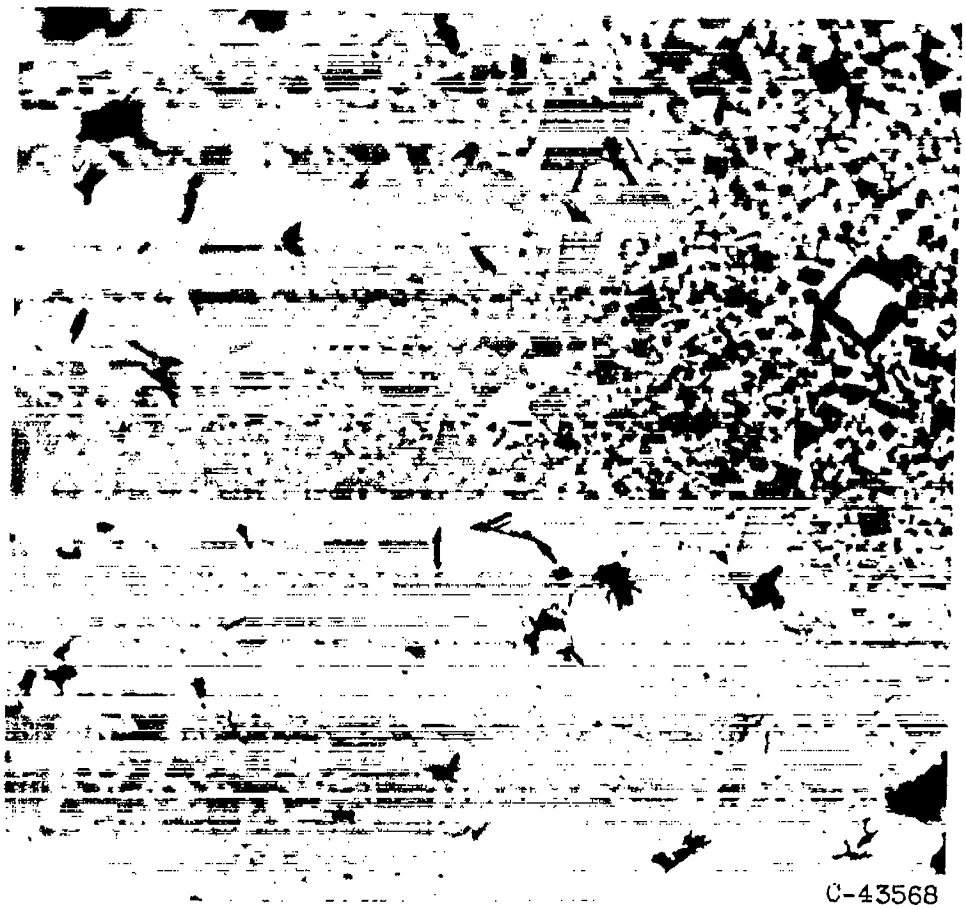
CD-3 back



(b) K152B (30 percent nickel).

Figure 4. - Continued. Microstructure of various titanium carbide base cermets. Unetched; X1000.

4105



C-43568

(c) K154B (50 percent nickel).

Figure 4. - Concluded. Microstructure of various titanium carbide base cermets. Unetched; X1000.

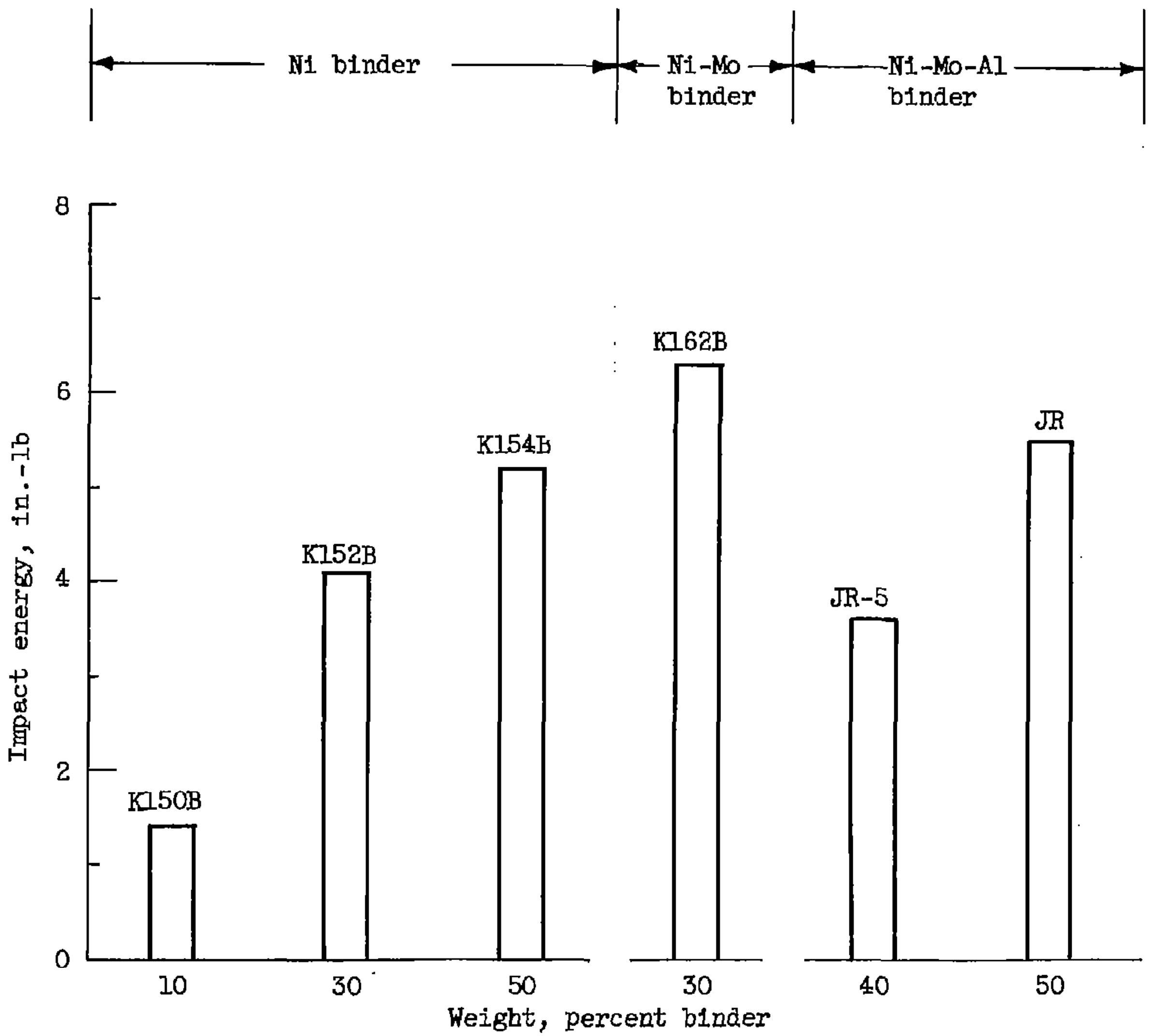


Figure 5. - Room-temperature impact resistance for liquid phase sintered, unnotched titanium carbide cermets.

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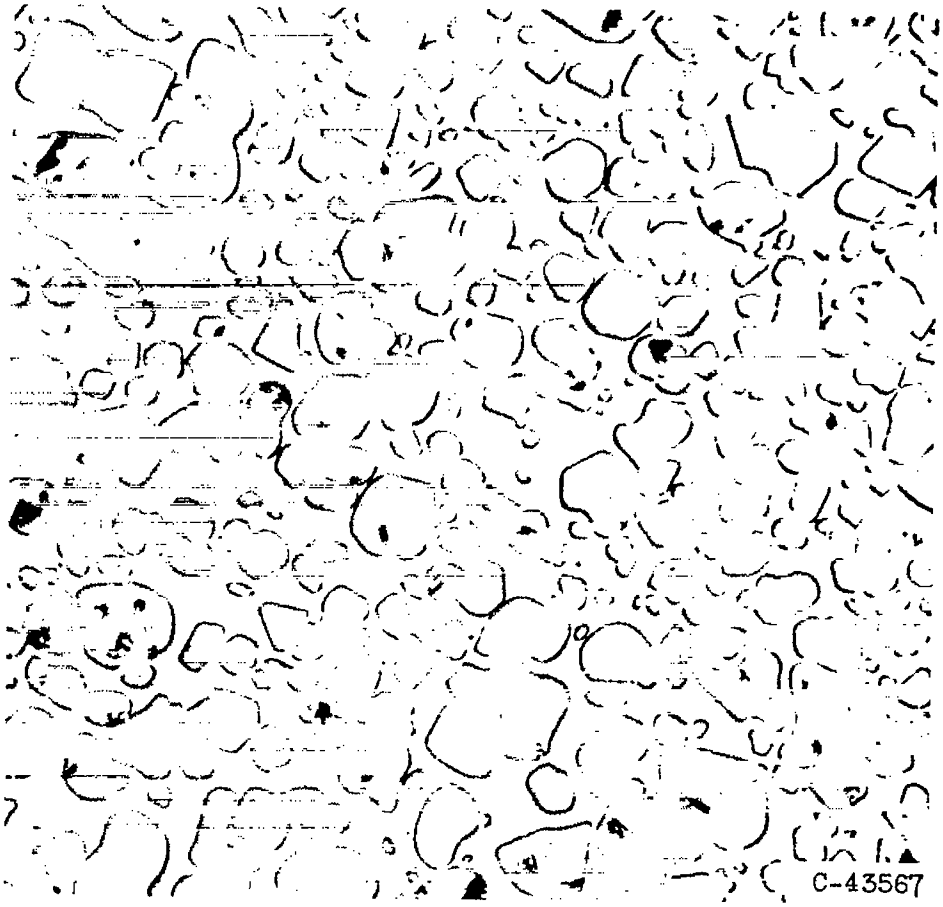

Figure 6. - Microstructure of infiltrated cermet TC-66-I (50 percent Inconel). Unetched; X1000.

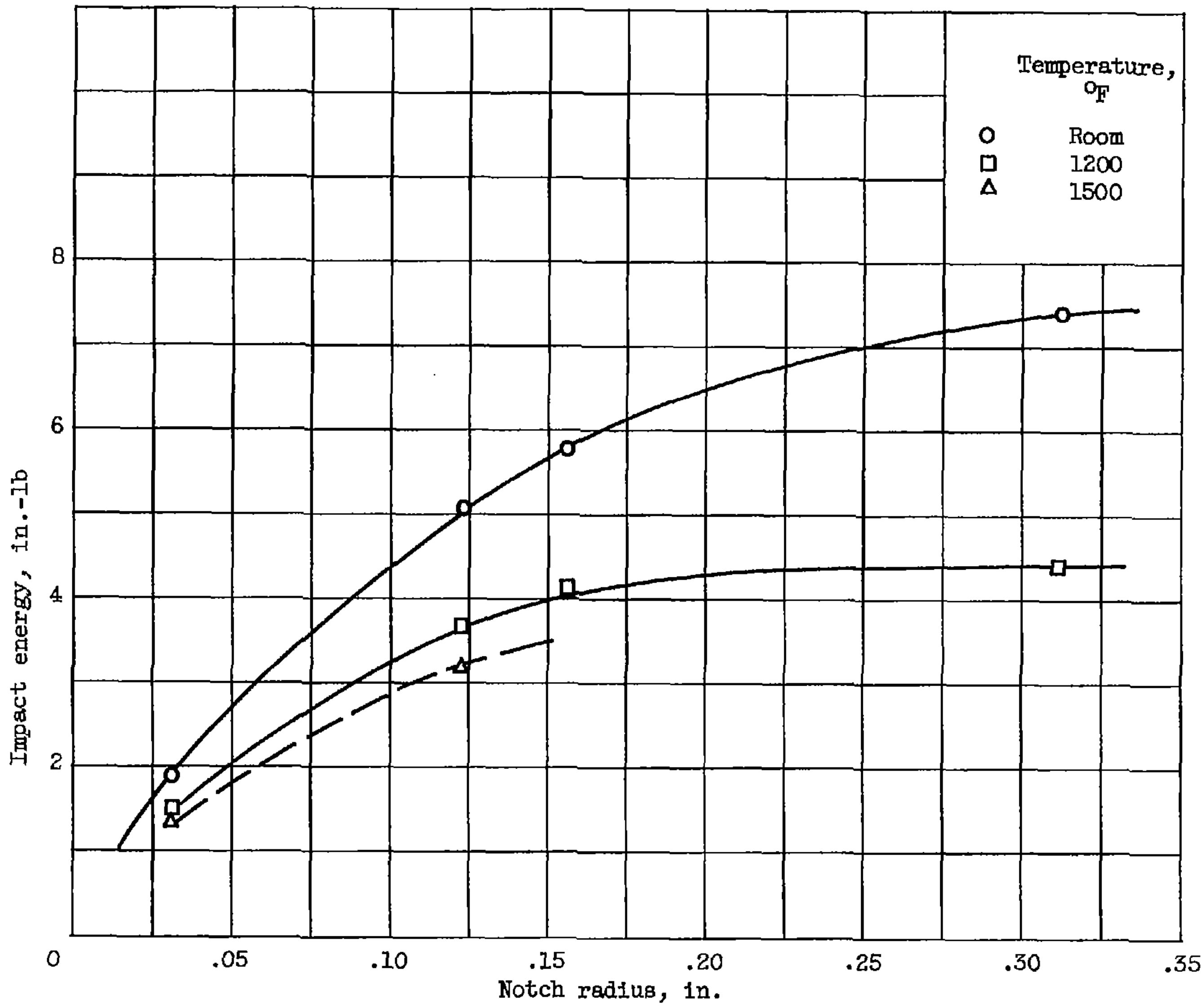

Figure 7. - Effect of notch radius on impact energy of K152B.